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(54) Continuously variable phase-shifter for electrically down-tilting an antenna

(57) A phase shifter for electrically adjusting the down-tilt of an antenna, based on rotating at least one phase wheel having a specially shaped dielectric. Each phase wheel is rotatably mounted between a stripline and the metallic ground plane of a feed system for an RF signal communicating the RF signal between each element of the antenna and a common terminal. The dielectric distributed on each phase wheel is shaped so that as the phase wheel is turned mechanically, the amount of dielectric directly beneath the stripline and above the metallic ground plane either increases or decreases in some proportion to the amount (angular displacement) the wheel is turned. All the phase wheels used in a system can be arranged, oriented, and tractively coupled so as to rotate in synchrony under the action of a single drive, which may itself be driven by a stepper motor for accurate, fine control. The phase wheels provide for continuous adjustment of the down-tilt of an antenna without having to convert between rotational and linear motion in moving dielectric into or out of position between the stripline and metallic ground plane.

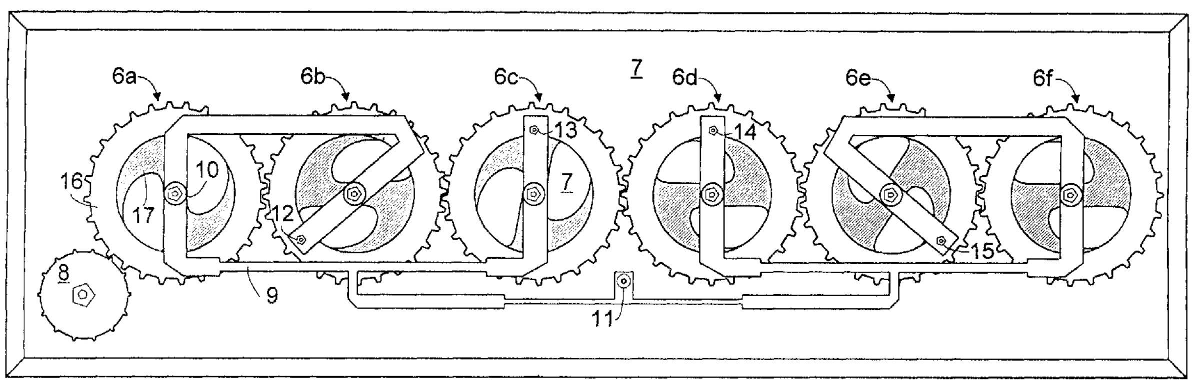

Fig. 2

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Description

TECHNICAL FIELD

The present invention pertains to the field of antennas. More particularly, this invention relates to electrically down-tilting the radiation pattern associated with a broadcast antenna, or, equivalently, electrically reorienting a receive antenna.

BACKGROUND OF THE INVENTION

It is sometimes desirable to adjust the orientation of a radiation pattern of a broadcast antenna. In particular, an adjustment downward is sometimes advantageous where a broadcast antenna is positioned at a higher altitude than other antennas that communicate with the broadcast antenna. This down-tilting of the radiation pattern alters the coverage angle and may reduce interference with nearby broadcast antennas, and may enhance communications with mobile users situated in valleys below the broadcast antenna. See "Electrical Downtilt Through Beam Steering Versus Mechanical Downtilt," by G. Wilson, IEEE 0-7803-0673-2/92, Vehicular Technology Conference 1992.

There are several approaches used to down-tilt the radiation pattern from an antenna. Besides actually tilting the entire antenna, which is generally regarded as too rigid an approach and too expensive, there is the approach that electrically down-tilts the pattern by adjusting the relative phases of the radiation associated with each of several elements of a multi-element antenna.

Among these electrical down-tilt methods is a capacitive coupling method, in which an adjustable capacitance is placed in series with the transmission line feeding each element of the antenna array, thus causing the desired phase shifts. Another such approach is to use different lengths of transmission lines for feeding the different elements; this produces a permanent electrical down-tilt. A third approach is to provide continuously adjustable down-tilting by mechanically varying the amount of dielectric material included in the transmission line, usually using a rack and pinion gear assembly.

Producing a fixed electrical phase shift is too rigid an approach for many applications. A fixed electrical phase shift solution cannot be altered to fit changing circumstances, and does not allow for optimizing the carrier-to-interference ratio.

Of the state-of-the art continuously variable electrical phase-shifting methods, the capacitive coupling method produces intermodulation products, and is generally only good for omni-directional antenna patterns. Existing methods of providing continuous phase shifting, for example using a rack and pinion assembly, are mechanically complex, and so are often unreliable and expensive. The complexity in these methods stems from translating rotational to linear motion in moving dielectric into or out of the transmission line.

It is well known in the art that a receive antenna responds to a radiation pattern in a way that is directly related to the radiation pattern the antenna would broadcast. Thus, the methods associated with down-tilting a broadcast antenna are equally applicable to adjusting a receive antenna to improve its reception in a particular direction.

SUMMARY OF THE INVENTION

The present invention is a continuously variable phase-shifter that electrically reorients the radiation pattern of a broadcast antenna by introducing more or less dielectric into the transmission line feeding the elements of the antenna, without ever converting rotational motion to linear motion. By avoiding having to convert linear motion to rotational motion in repositioning the dielectric material, the present invention overcomes the shortcomings of the prior art.

A phase-shifter according to the present invention is capable of varying continuously the down-tilt of a radiation pattern associated with an antenna, the radiation pattern comprising an RF signal, the antenna having a plurality of elements and having an element terminal for each element, and further having a feed system for communicating the RF signal between each element terminal and a common feed terminal, the feed system including a stripline spaced above a metallic ground plane. A phase shifter according to the present invention comprises:

- a phase wheel having a shaped dielectric distributed throughout, and rotatably positioned between the metallic ground plane and stripline so that, depending on the orientation of the phase wheel relative to the stripline, a particular amount of dielectric lies between the stripline and the metallic ground plane; and
- means for rotating the phase wheel relative to the stripline, whereby the amount of dielectric directly beneath the stripline and above the metallic ground plane can be varied, thereby causing the overall radiation pattern to vary in its down-tilt, the variation in down-tilting thus being produced by purely rotational mechanical motion.

Also according to the present invention, a phase-shifter may comprise additional phase wheels, each having distributed on it a shaped dielectric, each phase wheel rotatably positioned between the stripline and metallic ground plane, each phase wheel associated with one of the antenna elements, each phase wheel in tractive engagement with at least one of the other phase wheels in such an arrangement that all of the phase wheels are tractively coupled, and also comprising a means for turning one of the phase wheels, whereby all of the phase wheels are turned in synchrony, with each varying, as it is turned, the amount of dielectric directly beneath the stripline. In addition, all the phase wheels used in a system can be arranged, oriented, and tractively coupled so as to rotate in synchrony under the action of a single drive, which may itself be driven by a stepper motor for accurate, fine control.

Advantageously, throughout each phase wheel of a phase-shifter according to the present invention, the shaped dielectric is distributed so that as the phase wheel is turned, the amount of dielectric directly beneath the stripline, and between the stripline and the metallic ground plane, changes in direct proportion to an angular displacement of the phase wheel.

BRIEF DESCRIPTION OF THE DRAWINGS

The above features and advantages of the invention will become apparent from a consideration of the subsequent detailed description presented in connection with accompanying drawings, in which:

Figs. 1a-c show a phase wheel in three different orientations with respect to a stripline, which is part of the transmission line feeding an antenna element;
Fig. 2 shows an embodiment of the present invention for a four-element antenna, with six phase wheels all turned by a single drive gear; and
Figs. 3 shows a phase wheel having a dielectric with a dielectric constant of value greater than 4.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The detailed description will focus on the use of the present invention with a multi-element antenna broadcasting an RF signal. It should be understood, however, that the present invention is in fact intended equally for both broadcast and receive functions of an antenna system, and a likely use is as a component of a cellular communication base station antenna system. In that application, the phase shifter of the present invention would be suitable for electrically down-tilting the base station antenna over a band of frequencies in width perhaps as much as 20% of the central frequency.

Referring now to Figs. 1a-c, a phase wheel **6a** is shown mounted above a metallic ground plane **7** beneath a stripline **9** of a transmission line feeding an element of an antenna. The phase wheel **6a** holds a specially shaped dielectric **17**. As the phase wheel **6a** is rotated by means of its gear teeth **21**, more or less of the shaped dielectric **17** is positioned beneath the stripline **9**. In fact, the shaped dielectric **17**, in the preferred embodiment, is distributed on the phase wheel **6a** so that as the phase wheel **6a** is rotated, the dielectric beneath the stripline varies directly with an angular displacement (rotation by turning) of the phase wheel, the amount increasing or decreasing depending on the initial and final orientation of the phase wheel.

When the phase shifter of the present invention is used in an antenna system for broadcasting an RF signal, the electric field of the RF signal to be broadcast is concentrated between the metallic ground plane **7** and the stripline **9**. When a phase wheel is rotated so that more dielectric is positioned between the stripline and the ground plane, the RF signal is delayed, i.e., it is phase-shifted. Thus, the phase wheel **6a**, in the orientation illustrated in Fig. 1a, produces the greatest phase shift since as much dielectric as possible is directly beneath the stripline. In the orientation shown in Fig. 1b, the phase wheel **6a** produces less phase shift; and the phase wheel **6a** in the orientation shown in Fig. 1c produces the least phase shift of the three orientations.

In the preferred embodiment, a phase wheel **6a** is made as one piece by injection molding. The phase wheel has an annular ring **16** intended to hold the shaped dielectric **17** and to provide strength enough to rotate the phase wheel by its geared teeth **21**. Thus, the shaped dielectric **17** is ir addition to the dielectric of the annular ring **16**, which, in the preferred embodiment, is the same material since the entire phase wheel is injection molded. In the preferred embodiment, the thickness of the shaped dielectric **17** is approximately three times that of the annular ring **16**. This thickness is enough for some structural strength, in particular, it provides adequate strength for driving the phase wheel by its gear teeth, yet thin enough that the effect of the annular ring dielectric may be neglected in approximating the phase shift caused by a phase wheel. In other embodiments, the phase wheel annular ring is made of material different from the shaped dielectric, and for material that has a dielectric constant near air, the thickness is irrelevant in connection with producing a phase shift.

It is important that the shaped dielectric **17** be sized according to the wavelength of the RF signal in such a way as to reduce or eliminate reflected waves that occur whenever the RF signal encounters a change in impedance, i.e., whenever the RF signal first encounters or leaves the shaped dielectric. In the preferred embodiment, this is achieved by forming the phase wheel so that not only does it have an outer annular ring **16**, but also an inner core **20**, with none of the shaped dielectric **17**. With this configuration, when a phase wheel is oriented to provide some amount of phase shift of an RF signal, in traversing the phase wheel, the RF signal must enter and leave the shaped dielectric twice, once before the core, and once afterward. If each span of shaped dielectric encountered by the RF signal is one-quarter of a wavelength of the RF signal in that span (or odd integral multiples thereof), then, for a given span, the wave reflected on leaving is 180 degrees out of phase with respect to the wave reflected on entering the span, and the two waves cancel, producing no reflection.

When the phase wheel is rotated to produce minimum phase shift, the distance between the two starting points of the dielectric inside diameter of the annular ring is made to be one eighth the wavelength of the RF signal in whatever material occupies the volume between the stripline **9** and the metallic ground plane **7** outside of the shaped dielectric. In the preferred embodiment, this is air.

Thus, in the preferred embodiment, the radius **18a** in Fig. 1 should be one-eighth the wavelength of the RF signal in air, because in the preferred embodiment the space outside of the shaped dielectric, between the stripline and the metallic ground plane, is filled with air. (In other embodiments, this space may be filled with other dielectric materials.) In addition, the radius **18** shown in Fig. 1 should be one-quarter of the wavelength of the RF signal in the shaped dielectric **17**.

In arranging for this cancellation of reflected waves, the value of the dielectric constant of the shaped dielectric is taken into account. In Figs. 1a-c and Fig. 2, the shaped dielectric **17** fits inside the annular ring **16** having a constant inside radius **18a**. This occurs only when using a shaped dielectric **17** having a dielectric constant equal to the value 4, because of requiring, in the design of a phase wheel, that the diameter across the inside of the annular ring **16** be one-quarter of a wavelength of the RF signal in air, and also that this same diameter be one-half of the wavelength of the RF signal in the shaped dielectric. (This second requirement neglects the size of the core **20**, and follows from the requirement that at maximum phase shift the radius **18** be one-quarter of the wavelength of the RF signal to avoid reflected waves.) Thus, for a round shaped dielectric **17**, as shown in Fig. 1, we require that

$$D_{at\ \min imum} = \frac{\lambda_{air}}{4} \ and\ D_{at\ \max imum} = \frac{\lambda_{dielectric}}{2}$$

and for these two diameters to be the same, resulting in a round shaped dielectric, we therefore require that

$$\frac{\lambda_{air}}{4} = \frac{\lambda_{dielectric}}{2}$$

which yields the requirement that the shaped dielectric have a dielectric constant $K_e = 4$.

If the value is greater than 4, the shaped dielectric spans a smaller length, as shown in Fig. 3. If the value is less than four, the outer perimeter of the shaped dielectric deforms from circular in the opposite sense, so that it extends beyond the radius at minimum phase shift (radius **18a** in Fig. 3).

It is believed also possible to sometimes meet the antenna down-tilt requirements using phase wheels having shaped dielectrics with values other than 4, and yet that are not deformed either as in Fig. 3, or deformed in the opposite sense. This is done by designing the core **20** to vary in diameter so as to compensate for the two-fold requirement that the extent **18** be one-quarter of a wavelength of the RF signal in the dielectric, and that the extent **18a** be one-eighth of a wavelength of the RF signal in air. For example, to avoid deforming the shaped dielectric as in Fig. 3, the core **20** would be made larger in the orientation corresponding to maximum phase shift.

With the maximum phase shift per phase wheel taken to correspond to a quarter of the wavelength of the RF signal in the dielectric, the required dielectric constant K_e is:

$$K_e = [\pi/(\pi-\delta)]^2$$

in which δ is the maximum phase shift. For example, if the desired maximum phase shift is $\delta = 50°$ (0.87 radians), the dielectric constant K_e of the shaped dielectric **17** must be approximately 1.92.

Referring now to Fig. 2, an assembly of six phase wheels **6a-f**, geared to be mechanically synchronized, and all turned by a single drive gear **8**, are shown connected to input feed **11** to feed four elements of a planar antenna array (not shown) through outputs **12-15**, each output feeding a different antenna element. For accurate, fine control, the drive gear **8** is itself turned by a stepper motor.

Each phase wheel **6a-f** is fastened to the metallic ground plane **7** using a dielectric fastener **10**. The RF signal at output **12** is the most phase-shifted because the RF signal encounters the dielectric spanning the entire length of the stripline on top of the left-most phase wheel **6a**, and then some additional dielectric beneath the stripline spanning the phase wheel **6b**, second from left. In propagating from the input feed **11** to the output **13**, the RF signal encounters only the shaped dielectric **17** beneath the stripline spanning the phase wheel **6c**, and is therefore phase-shifted less than the RF signal arriving at output **12**. The RF signal at output **14** is the least phase-shifted.

With the phase wheels **6a-f** arranged together as shown in Fig. 2, because the dielectrics cause a phase difference between the RF signal issuing from the different antenna elements, the antenna beam is tilted up or down. The tilt, θ_t, for the assembly of Fig. 2, can be determined using the formula

$$\theta_t = \pi/2 - \cos^{-1}[\delta/(2\pi l)]$$

where l is the antenna element spacing.

It is possible to satisfy the down-tilting requirement of a four-element antenna with other than the particular combination of the six particular phase wheels used in the preferred embodiment, illustrated in Fig. 2. In this preferred embodiment, each phase wheel uses a shaped dielectric having a dielectric constant of value 4, and thus each phase wheel produces a maximum phase shift of 90°, and its shaped dielectric **17** is round, in the sense illustrated in Figs. 1a-c and Fig. 2.

The phase shifter of the present invention can be used in antennas with many different types of radiating elements, and can be used to tilt the radiation patterns of either uni-directional or omni-directional antennas. Although the preferred embodiment uses six phase wheels for a four-element planar antenna, the present invention is not limited to using six phase wheels for a four-element array, and is not limited to use with an antenna having four elements. In addition, this arrangement for continuously varying the phase shift of an antenna element can be used in an antenna system using a feed system that is series, binary, or any combination of series and binary feed systems.

Although in the present embodiment the shaped dielectric is formed to provide a linear relation between rotation and amount of dielectric beneath the stripline, the shape can be varied to produce other kinds of relationship. Also, as would be clear to one skilled in the art, a phase wheel according to the present invention can be fabricated from any type of dielectric material, including but not limited to plastic, ceramic and composite material.

It is to be understood that the above described arrangements are only illustrative of the application of the principles of the present invention. In particular, the phase-shifter of the present invention could be used with equal advantage in either a broadcast or receiver communication system. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention, and the appended claims are intended to cover such modifications and arrangements.

Claims

1. A phase-shifter capable of varying continuously the down-tilt of a radiation pattern associated with an antenna, the radiation pattern comprising an RF signal, the antenna having a plurality of elements and having an element terminal for each element, and further having a feed system for communicating the RF signal between each element terminal (12-15) and a common feed terminal (11), the feed system including a stripline (9) spaced above a metallic ground plane (7), the phase-shifter comprising:

a phase wheel (6a-f) having a shaped dielectric (17) distributed throughout, and rotatably positioned between the metallic ground plane (7) and the stripline (9) so that, depending on the orientation of the phase wheel relative to the stripline, a particular amount of dielectric lies directly beneath the stripline and above the metallic ground plane; and

means for rotating the phase wheel (6a-f) relative to the stripline (9),

whereby the amount of dielectric directly beneath the stripline and above the metallic ground plane can be varied, thereby causing the overall radiation pattern to vary in its down-tilt, the variation in down-tilting thus being produced by purely rotational mechanical motion.

2. A phase-shifter as claimed in claim 1, further comprising additional phase wheels, each having distributed on it a shaped dielectric, each phase wheel rotatably positioned between the stripline and metallic ground plane, each phase wheel associated with one of the antenna elements, each phase wheel in tractive engagement with at least one of the other phase wheels in such an arrangement that all of the phase wheels are tractively coupled, and also comprising a means for turning one of the phase wheels, whereby all of the phase wheels are turned in synchrony, with each varying, as it is turned, the amount of dielectric directly beneath the stripline.

3. A phase-shifter as claimed in claim 2, wherein, on each phase wheel (6a-f), the shaped dielectric (17) is distributed so that as the phase wheel is turned, the amount of dielectric directly beneath the stripline (9), and between the stripline (9) and the metallic ground plane (7), changes in direct proportion to an angular displacement of the phase wheel.

4. A phase-shifter as claimed in claim 2, wherein the shaped dielectric (17) is chosen to have a dielectric constant given by

$$K_e = [\pi/(\pi-\delta)]^2$$

where δ is the desired maximum phase shift that can be produced by the phase wheel.

5. A phase-shifter as claimed in claim 2, wherein the shaped dielectric (17) is distributed on the phase wheel (6a-f) so that when the phase wheel is oriented for maximum phase shift, positioning at least one continuous span of the shaped dielectric directly beneath the stripline (9), the continuous span of the shaped dielectric extends directly beneath the stripline over a length equal to an odd-integral multiple of one-quarter of the wavelength of the RF signal in the shaped dielectric, thereby providing for mutual cancellation of the two reflected waves produced as the RF signal traverses the continuous span of the shaped dielectric.

6. A phase-shifter as claimed in claim 2, wherein the shaped dielectric (17) is distributed on the phase wheel (6a-f) so that when the phase wheel is oriented for minimum phase shift, two continuous spans of the shaped dielectric are in position to be moved directly beneath the stripline (9) with any slight further turning of the phase wheel, and are separated by a medium, having a dielectric constant approximately the same as air, extending directly beneath the stripline over a length equal to an odd-integral multiple of one-quarter of the wavelength of the RF signal in the medium.

7. A phase-shifter as claimed in claim 1, wherein the shaped dielectric (17) is distributed so that as the phase wheel (6a-f) is turned, the amount of dielectric directly beneath the stripline (9), and between the stripline (9) and the metallic ground plane (7), changes in direct proportion to an angular displacement of the phase wheel.

8. A phase-shifter as claimed in claim 1, wherein the shaped dielectric (17) is chosen to have a dielectric constant given by

$$K_e = [\pi/(\pi-\delta)]^2$$

where δ is the desired maximum phase shift that can be produced by the phase wheel (6a-f).

9. A phase-shifter as claimed in claim 1, wherein the shaped dielectric (17) is distributed on the phase wheel (6a-f) so that when the phase wheel is oriented for maximum phase shift, positioning at least one continuous span of the shaped dielectric directly beneath the stripline (9), the continuous span of the shaped dielectric extends directly beneath the stripline over a length equal to an odd-integral multiple of one-quarter of the wavelength of the RF signal in the shaped dielectric, thereby providing for mutual cancellation of the two reflected waves produced as the RF signal traverses the continuous span of the shaped dielectric.

10. A phase-shifter as claimed in claim 1, wherein the shaped dielectric (17) is distributed on the phase wheel (6a-f) so that when the phase wheel is oriented for minimum phase shift, two continuous spans of the shaped dielectric are in position to be moved directly beneath the stripline (9) with any slight further turning of the phase wheel, and are separated by a medium, having a dielectric constant approximately the same as air, extending directly beneath the stripline over a length equal to an odd-integral multiple of one-quarter of the wavelength of the RF signal in the medium.

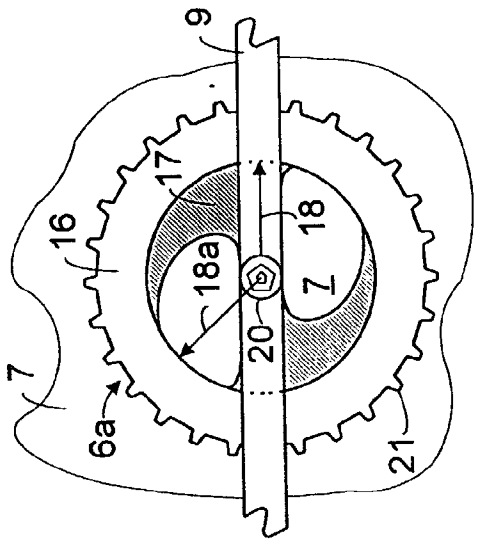

Fig. 1a

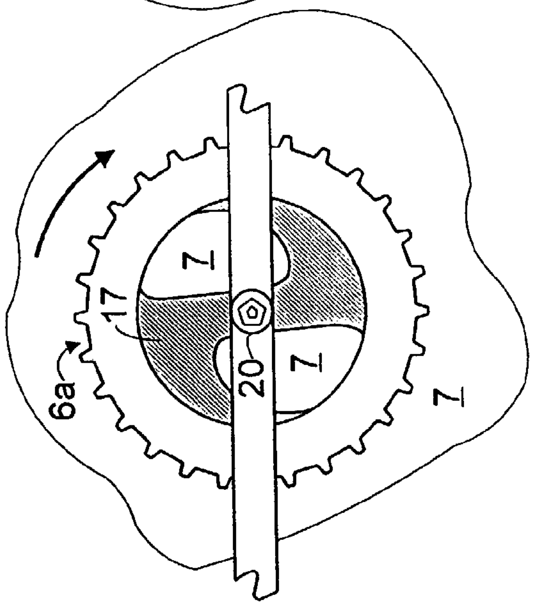

Fig. 1b

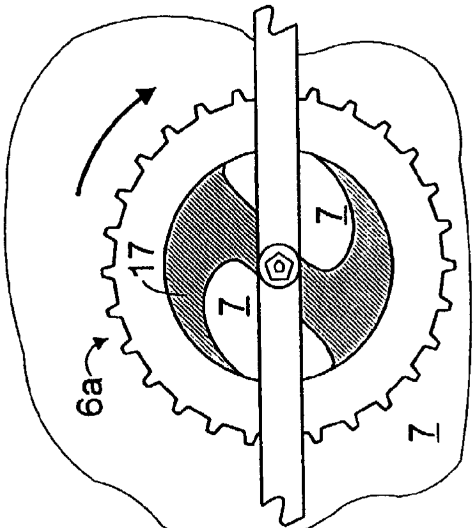

Fig. 1c

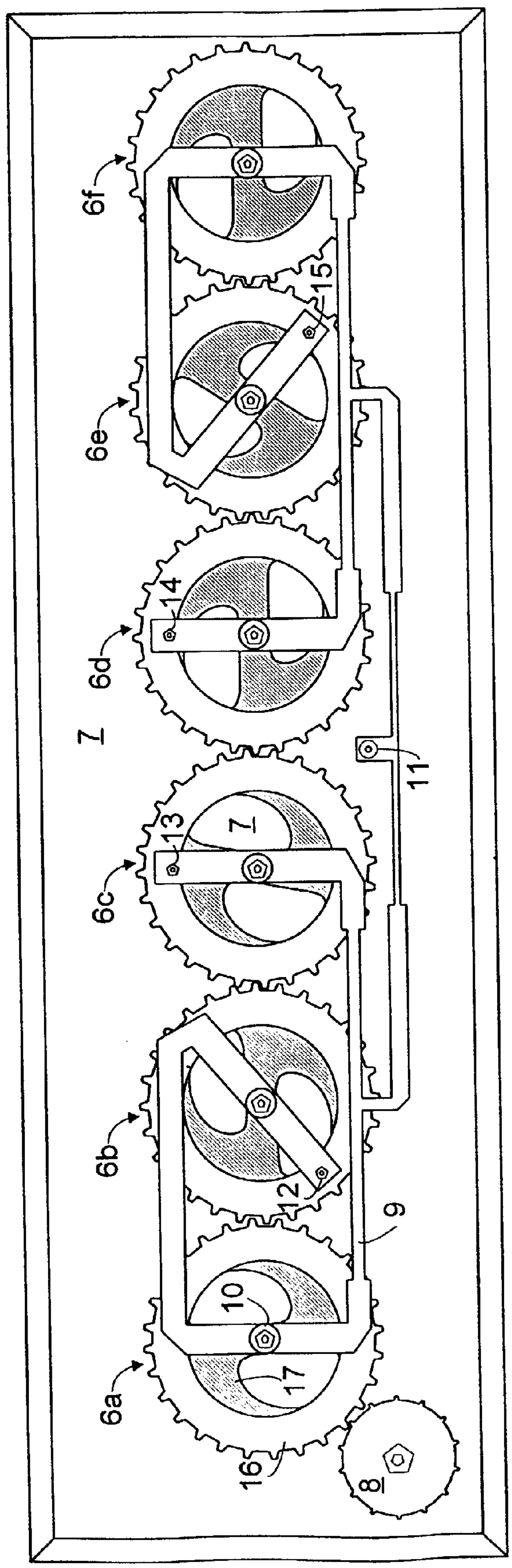

Fig. 2

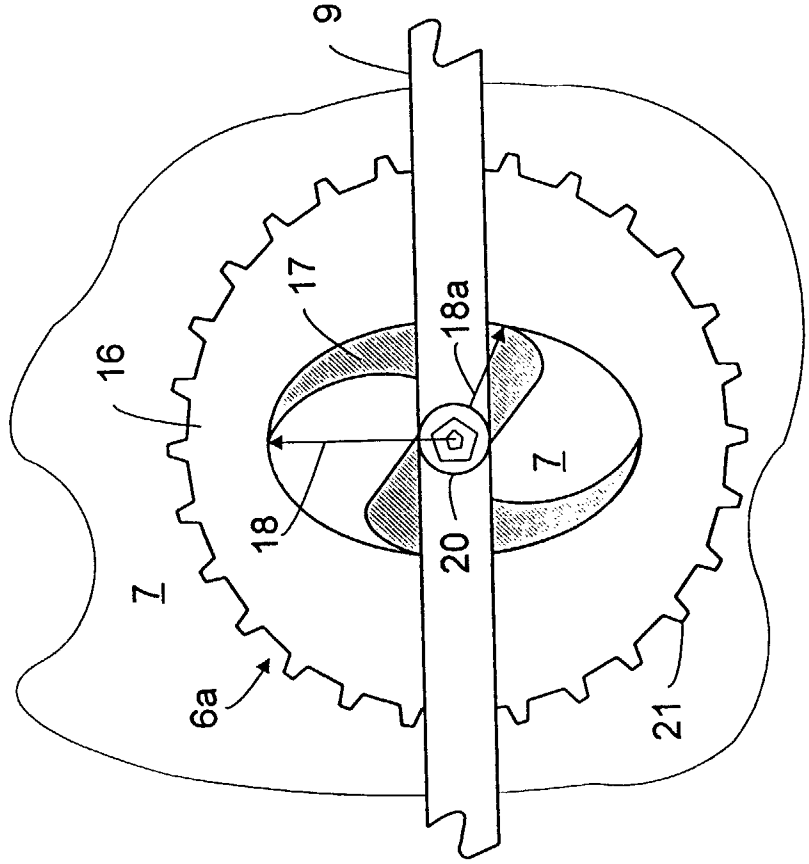

Fig. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 40 0302

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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A	GB 767 067 A (STANDARD TELEPHONES AND CABLES LIMITED) * page 2, line 95 - line 113; figures 8,9 * ---	1	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 May 1998	Den Otter, A

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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EUROPEAN SEARCH REPORT

Application Number
EP 98 40 0302

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP 0 456 579 A (THOMSON-CSF) 13 November 1991 * the whole document * -----	1	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

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